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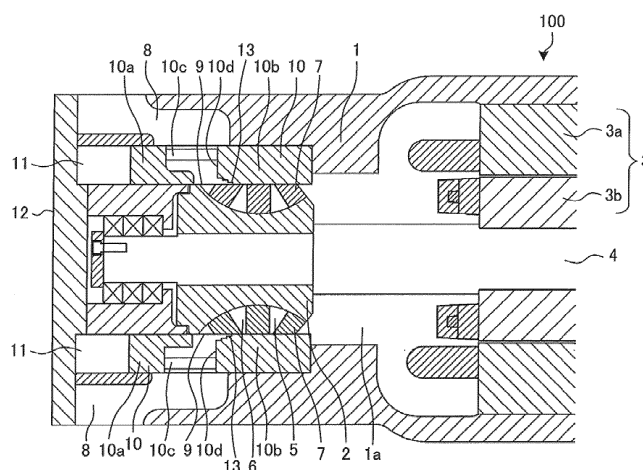
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(54) **SCREW COMPRESSOR AND REFRIGERATION CYCLE DEVICE**

(57) A highly efficient screw compressor and a refrigeration cycle apparatus simplifying control of a discharge port valve are obtained. The screw compressor includes: a casing body having a hollow part; a screw rotor rotating around a rotation shaft in the hollow part of the casing body; a semi-cylindrical groove formed on an outer side in a radial direction of the hollow part of the casing body

and extending in a direction of the rotation shaft of the screw rotor; and a discharge port valve contained in the semi-cylindrical groove, wherein an edge part of the discharge port valve, in which a discharge outlet facing an outer circumference of the screw rotor is opened, is formed into a stepped shape changing a flow path area of a discharge flow path in a stepwise manner.

FIG. 1



Description

Technical Field

5 **[0001]** The present invention relates to a screw compressor and a refrigeration cycle apparatus that do not require complex control.

Background Art

10 **[0002]** In a screw compressor, there is known a technique that includes a variable inner volume ratio valve, which is a slide valve adjusting a timing of starting discharge to make an inner volume ratio V_i adjustable, to thereby adjust an opening degree of the variable inner volume ratio valve by a driving force from a driving device in accordance with an operating pressure ratio (for example, refer to Patent Literature 1).

15 **[0003]** A conventional variable inner volume ratio valve used for the screw compressor is controlled as shown in Fig. 1 and Fig. 2 of Patent Literature 1. Specifically, upon calculating an optimum inner volume ratio value from a discharge pressure HP and a suction pressure LP and obtaining a current inner volume ratio value from a position detection unit, the variable inner volume ratio valve is controlled by a driving device coupled to the variable inner volume ratio valve so that a difference between the current inner volume ratio value and the optimum inner volume ratio value will be decreased. Further, to bring the current inner volume ratio value close to the optimum inner volume ratio value in actual operation, 20 the opening degree of the variable inner volume ratio valve is adjusted to minimize a motor driving power.

[0004] Here, the inner volume ratio V_i in the screw compressor is, for example, as disclosed in Patent Literature 2, a ratio between a tooth groove space volume in sucking and a tooth groove space volume just before discharging, and represents a ratio between a volume when suction is completed and a volume when a discharge port is opened.

25 **[0005]** Regarding a conventional discharge port valve, a discharge-side edge part of the discharge port valve facing an outer circumference of a screw rotor is formed into a corner-portion shape without steps in which an axial direction plane of a rotation shaft of the screw rotor and an orthogonal plane thereof are bent. Consequently, the minimum area of refrigerant flow in the discharge outlet, in which the refrigerant actually flows, becomes the size between the land part of the screw rotor and the discharge-side edge part of the discharge port valve. Therefore, when the timing to start opening the discharge outlet in the conventional discharge port valve of the fixed type is determined, the minimum area of refrigerant flow in the discharge outlet, in which the refrigerant actually flows, is automatically determined to be 30 broadened in accordance with the time course with rotation of the screw rotor.

[0006] If the inner volume ratio V_i is adapted to a low-load operation with a low compression ratio and a low flow rate that occupies the large part of operation time of an air-conditioning device per year, in a high-load operation with a high compression ratio and a high flow rate, a discharge outlet is opened at a discharge port before reaching the discharge 35 pressure. Further, since the minimum area of refrigerant flow in the discharge outlet after opening is large, a large amount of refrigerant gas flows back into a compression chamber, and thereby improper compression loss is generated.

[0007] On the other hand, if the inner volume ratio V_i is adapted to the high-load operation, in the low-load operation, the refrigerant gas is excessively compressed beyond the high-pressure side pressure until the discharge outlet is opened in the discharge port and the improper compression loss is increased by over compression, to thereby result in 40 deterioration of efficiency throughout the year.

Citation List

Patent Literature

45 **[0008]**

Patent Literature 1: Japanese Patent No. 4147891

Patent Literature 2: Japanese Unexamined Patent Application Publication No. 62-87687

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Summary of Invention

Technical Problem

55 **[0009]** Therefore, the screw compressor using the variable inner volume ratio valve has conventionally been suggested. However, a complex controller was required to control the variable inner volume ratio valve and there has been a problem of increased costs.

[0010] The present invention has been made to solve the above problem, and has an object to obtain a highly efficient

screw compressor and a refrigeration cycle apparatus simplifying control of a discharge port valve.

Solution to Problem

[0011] A screw compressor according to one embodiment of the present invention includes: a casing body having a hollow part; a screw rotor rotating around a rotation shaft in the hollow part of the casing body; a semi-cylindrical groove formed on an outer side in a radial direction of the hollow part of the casing body and extending in a direction of the rotation shaft of the screw rotor; and a discharge port valve contained in the semi-cylindrical groove, wherein an edge part of the discharge port valve, in which a discharge outlet facing an outer circumference of the screw rotor is opened, is formed into a stepped shape changing a flow path area of a discharge flow path in a stepwise manner.

[0012] A refrigeration cycle apparatus according to one embodiment of the present invention includes the above-described screw compressor.

Advantageous Effects of Invention

[0013] According to a screw compressor and a refrigeration cycle apparatus according to one embodiment of the present invention, an edge part of a discharge port valve, in which a discharge outlet facing an outer circumference of a screw rotor was opened, was formed into a stepped shape changing a flow path area of a discharge flow path in a stepwise manner. Therefore, the minimum area of refrigerant flow in the discharge outlet, in which the refrigerant actually flows, can be adjusted between a land part of the screw rotor and the edge part of the discharge port valve formed into the stepped shape corresponding to the time course with rotation of the screw rotor. In other words, in the edge part, which is formed into the stepped shape, of the discharge port valve, corresponding to the time course with rotation of the screw rotor, a position set to a minimum width facing the land part of the screw rotor is shifted in accordance with the stepped shape. Consequently, without requiring complex control for the discharge port valve, it is possible to reduce effects of improper compression loss in wide ranging operation conditions from a low compression ratio to a high compression ratio. Therefore, a simple and inexpensive configuration can be achieved, and the yearly operation efficiency can be increased.

Brief Description of Drawings

[0014]

Fig. 1 is a schematic configuration view of a screw compressor according to Embodiment 1 of the present invention.

Fig. 2A is a diagram illustrating a suction process included in the compression principles of the screw compressor according to Embodiment 1 of the present invention.

Fig. 2B is a diagram illustrating a compression process included in the compression principles of the screw compressor according to Embodiment 1 of the present invention.

Fig. 2C is a diagram illustrating a discharge process included in the compression principles of the screw compressor according to Embodiment 1 of the present invention.

Fig. 3A is a PV diagram illustrating a case of insufficient compression included in improper compression according to Embodiment 1 of the present invention.

Fig. 3B is a PV diagram illustrating a case of insufficient compression included in conventional improper compression.

Fig. 4A is a PV diagram illustrating a case of over compression included in the improper compression according to Embodiment 1 of the present invention.

Fig. 4B is a PV diagram illustrating a case of over compression included in the conventional improper compression.

Fig. 5A is a diagram illustrating a minimum area of the refrigerant flow in a discharge outlet at a start of opening thereof in the screw compressor according to Embodiment 1 of the present invention.

Fig. 5B is a diagram illustrating the minimum area of the refrigerant flow in the discharge outlet partway through opening thereof in the screw compressor according to Embodiment 1 of the present invention.

Fig. 5C is a diagram illustrating the minimum area of the refrigerant flow in the discharge outlet close to maximum opening thereof in the screw compressor according to Embodiment 1 of the present invention.

Fig. 6 is a diagram illustrating a relationship between a screw rotation angle of the screw compressor and the minimum area of the refrigerant flow according to Embodiment 1 of the present invention.

Fig. 7A is a diagram illustrating a minimum area of the refrigerant flow in a discharge outlet at a start of opening thereof in a conventional screw compressor.

Fig. 7B is a diagram illustrating the minimum area of the refrigerant flow in the discharge outlet partway through opening thereof in the conventional screw compressor.

Fig. 7C is a diagram illustrating the minimum area of the refrigerant flow in the discharge outlet close to maximum

opening thereof in the conventional screw compressor.

Fig. 8 is a diagram illustrating a relationship between a screw rotation angle of the conventional screw compressor and the minimum area of the refrigerant flow.

Fig. 9 is a schematic view illustrating a discharge port valve according to Embodiment 2 of the present invention.

Fig. 10 is an illustration diagram illustrating a cross section A-A of the discharge port valve shown in Fig. 9 according to Embodiment 2 of the present invention.

Fig. 11 is a schematic view illustrating a discharge port valve according to Embodiment 3 of the present invention.

Fig. 12 is an illustration diagram illustrating a cross section B-B of the discharge port valve shown in Fig. 11 according to Embodiment 3 of the present invention.

Fig. 13 is a schematic view illustrating a discharge port valve according to Embodiment 4 of the present invention.

Fig. 14 is an illustration diagram illustrating a cross section C-C of the discharge port valve shown in Fig. 13 according to Embodiment 4 of the present invention.

Fig. 15 is a refrigerant circuit diagram illustrating a refrigeration cycle apparatus to which a screw compressor according to Embodiment 5 of the present invention is applied.

Description of Embodiments

[0015] Hereinafter, the embodiments of the present invention will be described based on the attached drawings.

[0016] Note that those components assigned with the same signs in respective figures are the same or corresponding components, and this is common throughout the text of the specification.

[0017] Further, forms of constituent elements shown throughout the text in the specification are only examples, which do not limit the present invention to these descriptions.

Embodiment 1

(Configuration)

[0018] Fig. 1 is a schematic configuration view of a screw compressor 100 according to Embodiment 1 of the present invention. By use of Fig. 1, a schematic configuration of the screw compressor 100 will be described.

[0019] The screw compressor 100 according to Embodiment 1 is a single-screw compressor. The screw compressor 100 is used in a refrigeration cycle apparatus expected to operate in a wide range of compression ratio of, for example, an air-conditioning apparatus, a refrigeration device, a water heater and the like.

[0020] As shown in Fig. 1, the screw compressor 100 includes a cylindrical casing body 1 having a hollow part 1a inside thereof; and a screw rotor 2 contained in the hollow part 1a in the casing body 1.

[0021] In the shaft direction of the rotation shaft of the screw rotor 2, a motor 3 for rotationally driving the screw rotor 2 is included. The motor 3 is configured with a stator 3a fixed to the casing body 1 and a motor rotor 3b disposed inside the stator 3a with a gap. The rotation speed of the motor 3 is controlled by an inverter system, which is not shown.

[0022] The screw rotor 2 and the motor rotor 3b are mutually disposed on a same shaft line of the rotation shaft, and both of them are fixed to a screw shaft 4. The screw rotor 2 is coupled to the motor rotor 3b fixed to the screw shaft 4, to be rotationally driven.

[0023] On an outer circumferential surface of the screw rotor 2, multiple screw grooves 5 in a spiral shape are formed.

[0024] A compression chamber 6 of the screw compressor 100 is formed by the multiple screw grooves 5 in the spiral shape, an inner cylinder surface forming the hollow part 1a of the casing body 1, the screw rotor 2 and a pair of gate rotors 7 having multiple teeth engaged with the screw rotor 2.

[0025] In the casing body 1, a discharge pressure side and a suction pressure side are divided by a dividing wall, which is not-shown.

[0026] On the discharge pressure side of the casing body 1, a discharge outlet 9 opened in the discharge flow path 8 is formed.

[0027] On the inner cylinder surface of the casing body 1, there is formed a semi-cylindrical container groove 11 for a discharge port valve 10 projecting toward the outer side in the radial direction and extending in the direction of rotation shaft of the screw rotor 2. The container groove 11 corresponds to a semi-cylindrical groove of the present invention.

[0028] In the container groove 11, the discharge port valve 10 forming part of the discharge outlet 9 and the discharge flow path 8 is provided.

[0029] The discharge port valve 10 is fixed inside the container groove 11. The container groove 11 is opened on the left side of the figure to be closed by a lid material 12 on the left end part, in the figure, of the screw compressor 100. The opening of the container groove 11 is to insert the discharge port valve 10 into the container groove 11.

[0030] In the discharge port valve 10, a member 10a provided with a function of suppressing rotation of the discharge port valve 10 and a member 10b forming part of the discharge outlet 9 are integrated by providing a rod-shaped coupling

part 10c therebetween. The shape of the discharge port valve 10 is as shown in Figs. 9 to 14 in the embodiments to be described later.

[0031] An edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 changing a flow path area of the discharge flow path 8 in a stepwise manner. In other words, the stepped shape 13 is formed in the edge part, in which the discharge outlet 9 is opened, of the member 10b forming part of the discharge outlet 9 on the suction pressure side in the direction of rotation shaft.

[0032] The stepped shape 13 includes a single step or multiple steps; here, the stepped shape 13 is assumed to include N steps. The stepped shape 13 is formed only in the edge part, in which the discharge outlet 9 is opened, of the member 10b forming part of the discharge outlet 9. At an end part of the member 10b forming part of the discharge outlet 9 in the discharge port valve 10, the stepped shape 13 narrows the flow path width of the discharge flow path 8 in the rotation shaft direction in a stepwise manner from the discharge outlet 9 toward the outer side in the radial direction on the downstream side of the discharge flow path 8. Moreover, at an end part of the member 10b forming part of the discharge outlet 9 in the discharge port valve 10, the stepped shape 13 narrows the flow path area of the discharge flow path 8 in a stepwise manner from the member 10a provided with a function of suppressing rotation of the discharge port valve 10 toward the rotation shaft side on the upstream side of the discharge flow path 8.

[0033] The discharge port valve 10 forms the outside of the radial direction on the downstream side of the discharge flow path 8 in the stepped shape 13 narrowing the flow path area of the discharge flow path 8 in the stepwise manner on one end surface 10d on the side of the coupling part, and reduces the thickness of the member 10a provided with the function of suppressing rotation of the discharge port valve 10, to thereby broaden the flow path area of the discharge flow path 8. In other words, the discharge port valve 10 once narrows down the flow path area of the discharge flow path 8 from the discharge outlet 9, and thereafter enlarges thereof.

(Operation)

[0034] Next, operations of the screw compressor 100 according to Embodiment 1 will be described.

[0035] Fig. 2A is a diagram illustrating a suction process included in the compression principles of the screw compressor 100 according to Embodiment 1 of the present invention. Fig. 2B is a diagram illustrating a compression process included in the compression principles of the screw compressor 100 according to Embodiment 1 of the present invention. Fig. 2C is a diagram illustrating a discharge process included in the compression principles of the screw compressor 100 according to Embodiment 1 of the present invention.

[0036] As shown in Figs. 2A to 2C, the screw rotor 2 is rotated by the motor 3 via the screw shaft 4, and thereby the teeth of the gate rotor 7 relatively move in the screw grooves 5 forming the compression chamber 6. Consequently, assuming that the suction process, the compression process and the discharge process constitute one cycle, the one cycle is repeated in the compression chamber 6. Here, focusing on the compression chamber 6 enclosed by the bold lines in Figs. 2A to 2C, each of the processes will be described.

[0037] Fig. 2A shows a state of the compression chamber 6 in the suction process. The screw rotor 2 is driven by the motor 3 to be rotated in the direction of the solid-line arrow. This reduces the volume of the compression chamber 6 as shown in Fig. 2B, and thereby the compression process is performed.

[0038] When the screw rotor 2 is subsequently rotated, as shown in Fig. 2C, the compression chamber 6 is communicated to the discharge outlet 9 formed by the inner cylinder surface of the casing body 1 and the discharge port valve 10, and thereby the discharge process is performed. Consequently, the high-pressure refrigerant gas compressed in the compression chamber 6 passes through the discharge flow path 8 from the discharge outlet 9, and is discharged to the outside of the screw compressor 100. Then, on the back of the screw rotor 2, similar compression is performed again.

(Effect)

[0039] Next, effects of the screw compressor 100 according to Embodiment 1 will be described.

[0040] Fig. 3A is a PV diagram illustrating a case of insufficient compression included in improper compression according to Embodiment 1 of the present invention. Fig. 3B is a PV diagram illustrating a case of insufficient compression included in conventional improper compression. Fig. 4A is a PV diagram illustrating a case of over compression included in the improper compression according to Embodiment 1 of the present invention. Fig. 4B is a PV diagram illustrating a case of over compression included in the conventional improper compression. Fig. 5A is a diagram illustrating a minimum area S of the refrigerant flow in the discharge outlet 9 at a start of opening thereof in the screw compressor 100 according to Embodiment 1 of the present invention. Fig. 5B is a diagram illustrating the minimum area S of the refrigerant flow in the discharge outlet 9 partway through opening thereof in the screw compressor 100 according to Embodiment 1 of the present invention. Fig. 5C is a diagram illustrating the minimum area S of the refrigerant flow in the discharge outlet 9 close to maximum opening thereof in the screw compressor 100 according to Embodiment 1 of the present invention.

Fig. 6 is a diagram illustrating a relationship between a screw rotation angle of the screw compressor 100 and the minimum area S of the refrigerant flow according to Embodiment 1 of the present invention. Fig. 7A is a diagram illustrating a minimum area S of the refrigerant flow in a discharge outlet at a start of opening thereof in a conventional screw compressor. Fig. 7B is a diagram illustrating the minimum area S of the refrigerant flow in the discharge outlet partway through opening thereof in the conventional screw compressor. Fig. 7C is a diagram illustrating the minimum area S of the refrigerant flow in the discharge outlet close to maximum opening thereof in the conventional screw compressor. Fig. 8 is a diagram illustrating a relationship between a screw rotation angle of the conventional screw compressor and the minimum area S of the refrigerant flow.

[0041] In the case of insufficient compression shown in Fig. 3B, the compression chamber is communicated to the discharge outlet before the refrigerant gas pressure in the compression chamber reaches a high pressure P_d . In other words, in the conventional screw compressor, as shown in Figs. 7A to 7C, the minimum area S of the refrigerant flow in the discharge outlet, in which the refrigerant actually flows, is automatically determined to be broadened in accordance with the time course with rotation of the screw rotor. As shown in Fig. 8, the minimum area S of the refrigerant flow is broadened from the start of opening corresponding to the screw rotation angle. Therefore, as shown in Fig. 7A, the discharge outlet is opened in the discharge port before reaching the discharge pressure. Further, as shown in Fig. 7B, the minimum area S of the refrigerant flow in the discharge outlet after opening is large. Consequently, the refrigerant gas in the discharge flow path flows from the discharge outlet back into the compression chamber, to thereby result in a pattern of conventional compression P_2 in which the pressure is sharply increased as compared to a pattern of ideal compression P_{id} . Consequently, increase in power by the area of the shaded portion results in a loss as insufficient compression loss.

[0042] On the other hand, as shown in Figs. 5A to 5C, in Embodiment 1, in the operation conditions of a high operation load factor with a high compression ratio and a high frequency, the minimum area S of the refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, can be adjusted to be narrowed, not to be broadened, at the start of opening between the land part 2a of the screw rotor 2 and the edge part of the discharge port valve 10 formed into the stepped shape 13 corresponding to the time course with rotation of the screw rotor 2. The adjustment portion in which the minimum area S of the refrigerant flow is adjusted not to be broadened at the start of opening is the portion A in the bumped shape of a single stage shown in Fig. 6. As described above, in the edge part of the discharge port valve 10, which is formed into the stepped shape 13, corresponding to the time course with rotation of the screw rotor 2, a position set to a minimum width facing the land part 2a of the screw rotor 2 is shifted in accordance with the stepped shape 13. Therefore, as shown in Fig. 5B, at the timing of occurrence of backflow of the refrigerant gas into the compression chamber 6 due to insufficient compression immediately after communicating to the discharge outlet 9, the minimum area S of the refrigerant flow is maintained to be small. Accordingly, the compression results in a pattern of performed compression P_1 shown in Fig. 3A, thereby the power loss by the area of the shaded portion is improved, and it is possible to keep the effect of increase in power due to backflow of the refrigerant gas to be small.

[0043] In the case of over compression shown in Fig. 4B, since the compression is continued until the refrigerant gas pressure in the compression chamber 6 reaches the volume V_d after reaching the high pressure P_d , the compression results in the pattern of the conventional compression P_4 . Consequently, increase in power by the area of the shaded portion results in a loss as over compression loss.

[0044] On the other hand, in Embodiment 1, in the operation conditions of a low operation load factor with a low compression ratio and a low frequency, the compression results in a pattern of performed compression P_3 shown in Fig. 4A due to a small refrigerant circulation amount, thereby the power loss by the area of the shaded portion is improved, and it is possible to keep the effect of discharge pressure loss to be small, and to keep the effect of increase in power to be small.

[0045] As described above, in Embodiment 1, the edge part of the discharge port valve 10, in which the discharge outlet 9 is opened, is formed into the stepped shape 13 of N steps.

[0046] With the configuration, the stepped shape 13 makes it difficult to broaden the minimum area S of the refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, immediately after the screw grooves 5 are communicated to the discharge outlet 9. Then, thereafter, the minimum area S of the refrigerant flow is broadened with the movement of the screw grooves 5 toward the discharge side.

[0047] Consequently, in the operation conditions of the low operation load factor with the low compression ratio and the low frequency, due to a small refrigerant circulation amount, it is possible to keep the effect of discharge pressure loss to be small, and to keep the effect of increase in power to be small.

[0048] On the other hand, in the operation conditions of the high operation load factor with the high compression ratio and the high frequency, there is the timing when, immediately after communicating to the discharge outlet 9, backflow of the refrigerant gas into the compression chamber 6 due to insufficient compression is likely to occur. At this time, the position set to the minimum width facing the land part 2a of the screw rotor 2 is shifted in accordance with the stepped shape 13, and thereby the minimum area S of the refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, is narrowed down. Accordingly, it is possible to keep the effect of increase in power due to backflow of

the refrigerant gas to be small.

[0049] In other words, according to Embodiment 1, it is possible to form the minimum area S of the refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, corresponding to wide operating pressure ratio without sliding the discharge port valve 10, and thereby the high-performance screw compressor 100 in the wide operation range can be obtained.

[0050] Moreover, since a variable inner volume ratio mechanism and control for causing the discharge port valve 10 to serve as the variable inner volume ratio valve are unnecessary, a compact and inexpensive screw compressor 100 can be obtained.

Embodiment 2

[0051] In Embodiment 1, the number of steps in the stepped shape 13 was assumed to be N steps including a single step and multiple steps. In Embodiment 2, description will be given of a configuration when the number of steps is assumed to be one, namely, N = 1. Note that, in Embodiment 2, it is assumed that different points from Embodiment 1 will be described, and components not described in Embodiment 2 are the same as those of Embodiment 1.

[0052] Fig. 9 is a schematic view illustrating a discharge port valve 10 according to Embodiment 2 of the present invention. Fig. 10 is an illustration diagram illustrating a cross section A-A of the discharge port valve 10 shown in Fig. 9 according to Embodiment 2 of the present invention.

[0053] In the discharge port valve 10, a member 10a provided with a function of suppressing rotation of the discharge port valve 10 and a member 10b forming part of the discharge outlet 9 are integrated by providing a rod-shaped coupling part 10c therebetween.

[0054] The discharge port valve 10 is formed on the outer side in the radial direction of the hollow part 1a of the casing body 1 and contained in the semi-cylindrical container groove 11 extending in the direction of the rotation shaft of the screw rotor 2, and fixed thereto.

[0055] The edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 with a single step shifting the position thereof toward the outer side in the radial direction on the downstream side of the discharge flow path 8.

[0056] The stepped shape 13 with a single step refers to a shape having a step end surface 10e of a single step and two surfaces 10f arranged in line along the outer circumference of the screw rotor 2.

[0057] Here, regarding the refrigeration cycle apparatus, other than a coefficient of performance COP indicating energy consumption efficiency, there is an integrated part load value IPLV that is a coefficient of performance of a refrigeration cycle apparatus during a period. In the Air-Conditioning and Refrigeration Institute (ARI), the integrated part load value IPLV is calculated by the following calculation formula:

$$\text{IPLV} = 0.01 \times A + 0.42 \times B + 0.45 \times C + 0.12 \times D,$$

where

A = COP with a load of 100%, B = COP with a load of 75%,
C = COP with a load of 50%, and D = COP with a load of 25%.

[0058] According to the calculation formula, the coefficient of performance differs in response to the load in operation; moreover, the time with the load of 75% occupies 42% of the annual operation time and the time with the load of 50% occupies 45% of the annual operation time, and therefore, the weight is larger in these two conditions.

[0059] Moreover, in the Japan Refrigeration and Air Conditioning Industry Association (JRAIA), a similar index is defined as in the following formula.

$$\text{IPLV} = 0.01 \times A + 0.47 \times B + 0.37 \times C + 0.15 \times D,$$

where

A = COP with a load of 100%, B = COP with a load of 75%,
C = COP with a load of 50%, and D = COP with a load of 25%.

[0060] In this manner, similar to the Air-Conditioning and Refrigeration Institute (ARI), the weight is different in each

operation load factor. In other words, the time with the load of 75% occupies 47% of the annual operation time and the time with the load of 50% occupies 37% of the annual operation time, and therefore, the weight is larger in these two conditions.

[0061] In Embodiment 2, one step end surface 10e of the stepped shape 13 and one end surface 10d closer to the coupling part 10c in the discharge port valve 10 are formed with end surface inclination optimized in the two conditions having a large weight of the integrated part load value IPLV.

[0062] In other words, two end surface inclinations are formed by optimization in the two conditions B and C having a large weight of the integrated part load value IPLV.

[0063] The end surface inclination is formed into a curved surface shape corresponding to a discharge side end of the land in the screw rotor, which the discharge port valve, not in the conventional stepped shape, in the two conditions B and C in the sliding position faces.

[0064] With the configuration, it is possible to obtain the screw compressor 100 having high integrated part load value IPLV. Moreover, since the discharge port valve 10 does not require a mechanism for serving as the variable inner volume ratio valve and control, the screw compressor 100, which is more compact and less expensive than a conventional one, can be obtained.

Embodiment 3

[0065] In Embodiment 2, it was assumed that the number of steps in the stepped shape 13 was one, namely, $N = 1$. In Embodiment 3, description will be given of a configuration when the number of steps is assumed to be two, namely, $N = 2$. Note that, in Embodiment 3, it is assumed that different points from Embodiments 1 and 2 will be described, and components not described in Embodiment 3 are the same as those of Embodiment 1.

[0066] Fig. 11 is a schematic view illustrating the discharge port valve 10 according to Embodiment 3 of the present invention. Fig. 12 is an illustration diagram illustrating a cross section B-B of the discharge port valve 10 shown in Fig. 11 according to Embodiment 3 of the present invention.

[0067] In the discharge port valve 10, a member 10a provided with a function of suppressing rotation of the discharge port valve 10 and a member 10b forming part of the discharge outlet 9 are integrated by providing a rod-shaped coupling part 10c therebetween.

[0068] The discharge port valve 10 is formed on the outer side in the radial direction of the hollow part 1a of the casing body 1 and contained in the semi-cylindrical container groove 11 extending in the direction of the rotation shaft of the screw rotor 2, and fixed thereto.

[0069] The edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 with two steps shifting the position thereof toward the outer side in the radial direction on the downstream side of the discharge flow path 8.

[0070] The stepped shape 13 with two steps refers to a shape having a step end surface 10e of two steps and three surfaces 10f arranged in line along the outer circumference of the screw rotor 2.

[0071] In Embodiment 3, two step end surfaces 10e of the stepped shape 13 and one end surface 10d closer to the coupling part 10c in the discharge port valve 10 are formed with end surface inclination optimized in three conditions having a large weight of the integrated part load value IPLV shown in Embodiment 2.

[0072] In other words, three end surface inclinations are formed by optimization in the three conditions B, C and D having a large weight of the integrated part load value IPLV.

[0073] The end surface inclination is formed into a curved surface shape corresponding to a discharge side end of the land in the screw rotor, which the discharge port valve, not in the conventional stepped shape, in the three conditions B, C and D in the sliding position faces.

[0074] With the configuration, it is possible to obtain the screw compressor 100 having higher integrated part load value IPLV than Embodiment 2. Moreover, since the discharge port valve 10 does not require a mechanism for serving as the variable inner volume ratio valve and control, the screw compressor 100, which is more compact and less expensive than a conventional one, can be obtained.

Embodiment 4

[0075] In Embodiment 3, it was assumed that the number of steps in the stepped shape 13 was two, namely, $N = 2$. In Embodiment 4, description will be given of a configuration when the number of steps is assumed to be three, namely, $N = 3$. Note that, in Embodiment 4, it is assumed that different points from Embodiments 1 to 3 will be described, and components not described in Embodiment 4 are the same as those of Embodiment 1.

[0076] Fig. 13 is a schematic view illustrating the discharge port valve 10 according to Embodiment 4 of the present invention. Fig. 14 is an illustration diagram illustrating a cross section C-C of the discharge port valve 10 shown in Fig. 13 according to Embodiment 4 of the present invention.

[0077] In the discharge port valve 10, a member 10a provided with a function of suppressing rotation of the discharge port valve 10 and a member 10b forming part of the discharge outlet 9 are integrated by providing a rod-shaped coupling part 10c therebetween.

[0078] The discharge port valve 10 is formed on the outer side in the radial direction of the hollow part 1a of the casing body 1 and contained in the semi-cylindrical container groove 11 extending in the direction of the rotation shaft of the screw rotor 2, and fixed thereto.

[0079] The edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 with three steps shifting the position thereof toward the outer side in the radial direction on the downstream side of the discharge flow path 8.

[0080] The stepped shape 13 with three steps refers to a shape having a step end surface 10e of three steps and four surfaces 10f arranged in line along the outer circumference of the screw rotor 2.

[0081] In Embodiment 4, three step end surfaces 10e of the stepped shape 13 and one end surface 10d closer to the coupling part 10c in the discharge port valve 10 are formed with end surface inclination optimized in four conditions A, B, C and D of the integrated part load value IPLV.

[0082] The end surface inclination is formed into a curved surface shape corresponding to a discharge side end of the land in the screw rotor, which the discharge port valve, not in the conventional stepped shape, in the four conditions A, B, C and D in the sliding position faces.

[0083] With the configuration, it is possible to obtain the screw compressor 100 having higher integrated part load value IPLV than Embodiment 3. Moreover, since the discharge port valve 10 does not require a mechanism for serving as the variable inner volume ratio valve and control, the screw compressor 100, which is more compact and less expensive than a conventional one, can be obtained.

Embodiment 5

[0084] Fig. 15 is a refrigerant circuit diagram illustrating a refrigeration cycle apparatus 200 to which the screw compressor 100 according to Embodiment 5 of the present invention is applied.

[0085] As shown in Fig. 15, the refrigeration cycle apparatus 200 includes the screw compressor 100, a condenser 80, an expansion valve 81 and an evaporator 82. These screw compressor 100, condenser 80, expansion valve 81 and evaporator 82 are connected via the refrigerant pipe to form the refrigeration cycle circuit. The refrigerant flowing out of the evaporator 82 is sucked into the screw compressor 100 to have high temperature and high pressure. The refrigerant that became high temperature and high pressure is condensed in the condenser 80 to become liquid. The refrigerant that became liquid is subjected to pressure reduction and expansion by the expansion valve 81 to enter a two-phase gas-liquid state of low temperature and low pressure, and thereby the two-phase gas-liquid refrigerant is subjected to heat exchange in the evaporator 82.

[0086] The screw compressors 100 in the Embodiments 1 to 4 can be applied to such a refrigeration cycle apparatus 200. Note that examples of the refrigeration cycle apparatus 200 include an air-conditioning apparatus, a refrigeration device, a water heater and the like.

[0087] According to the above-described Embodiments 1 to 5, the screw compressor 100 includes the casing body 1 having the hollow part 1a. The screw compressor 100 also includes the screw rotor 2 rotating around the rotation shaft in the hollow part 1a of the casing body 1. The screw compressor 100 also includes a semi-cylindrical container groove 11 formed on the outer side in the radial direction of the hollow part 1a of the casing body 1 and extending in the direction of the rotation shaft of the screw rotor 2. The screw compressor 100 also includes the discharge port valve 10 contained in the container groove 11. The edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 changing a flow path area of the discharge flow path 8 in a stepwise manner.

[0088] With the configuration, the edge part of the discharge port valve 10, in which the discharge outlet 9 facing an outer circumference of the screw rotor 2 is opened, is formed into a stepped shape 13 changing a flow path area of the discharge flow path 8 in a stepwise manner. Therefore, the minimum area S of refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, can be adjusted between a land part 2a of the screw rotor 2 and the edge part of the discharge port valve 10 formed into the stepped shape 13 corresponding to the time course with the rotation of the screw rotor 2. In other words, in the edge part of the discharge port valve 10, which is formed into the stepped shape 13, corresponding to the time course with the rotation of the screw rotor 2, a position set to a minimum width facing the land part 2a of the screw rotor 2 is shifted in accordance with the stepped shape 13. Consequently, without requiring complex control for the discharge port valve 10, it is possible to reduce effects of improper compression loss in wide ranging operation conditions from a low compression ratio to a high compression ratio. Therefore, a simple and inexpensive configuration can be achieved, and the yearly operation efficiency can be increased.

[0089] In the discharge port valve 10, a member 10a provided with a function of suppressing rotation of the discharge port valve 10 and a member 10b forming part of the discharge outlet 9 are integrated by providing a rod-shaped coupling

part 10c therebetween. The stepped shape 13 is formed in the edge part, in which the discharge outlet 9 is opened, of the member 10b forming part of the discharge outlet 9.

[0090] With the configuration, it is possible to simplify the control of the discharge port valve 10 to form the minimum area S of the refrigerant flow in the discharge outlet 9, in which the refrigerant actually flows, corresponding to wide operating pressure ratio and thereby the high-performance screw compressor 100 in the wide operation range can be obtained.

[0091] Moreover, since the control for causing the discharge port valve 10 to serve as the variable inner volume ratio valve is simplified, a compact and inexpensive screw compressor 100 can be obtained.

[0092] The discharge port valve 10 is fixed.

[0093] With the configuration, it is possible to form the discharge flow path 8 corresponding to wide operating pressure ratio without sliding the discharge port valve 10, and thereby the high-performance screw compressor 100 in the wide operation range can be obtained.

[0094] Moreover, since a variable inner volume ratio mechanism and control for causing the discharge port valve 10 to serve as the variable inner volume ratio valve are unnecessary, a compact and inexpensive screw compressor 100 can be obtained.

[0095] The stepped shape 13 includes a single step and end surface inclination of the stepped shape 13 is formed by optimization in two conditions having a large weight of the integrated part load value IPLV.

[0096] With the configuration, it is possible to obtain the screw compressor 100 having high integrated part load value IPLV.

[0097] The stepped shape 13 includes two steps and end surface inclination of the stepped shape 13 is formed by optimization in three conditions having a large weight of the integrated part load value IPLV.

[0098] With the configuration, it is possible to obtain the screw compressor 100 having high integrated part load value IPLV.

[0099] The stepped shape 13 includes three steps and end surface inclination of the stepped shape 13 is formed by optimization in four conditions having a large weight of the integrated part load value IPLV.

[0100] With the configuration, it is possible to obtain the screw compressor 100 having high integrated part load value IPLV.

[0101] The refrigeration cycle apparatus 200 includes the screw compressor 100.

[0102] With the configuration, a simple and inexpensive configuration can be achieved, and the yearly operation efficiency can be increased.

[0103] Note that, in the above-described embodiments, the discharge port valve 10 was fixed inside the container groove 11. However, the discharge port valve 10 may be driven by control in which, for example, the drive patterns are simplified into only two patterns or others. Even in such a case, it is possible to improve the improper compression loss by simplifying the control. Moreover, the above-described stepped shape 13 may be applied to a slide valve capable of adjusting the compression capacity.

[0104] Moreover, in the above-described embodiments, description was given by using the single-screw compressor as the screw compressor. However, other than this, a twin-screw compressor may be used as the screw compressor.

Reference Signs List

[0105] 1 casing body 1a hollow part 2 screw rotor 2a land part 3 motor 3a stator 3b motor rotor 4 screw shaft 5 screw groove 6 compression chamber 7 gate rotor 8 discharge flow path 9 discharge outlet 10 discharge port valve 10a member provided with function of suppressing rotation of discharge port valve 10b member forming part of discharge outlet 10c coupling part 10d end surface closer to coupling part 10e step end surface 10f surface along outer circumference of screw rotor 11 container groove 12 lid material 13 stepped shape 80 condenser 81 expansion valve 82 evaporator 100 screw compressor 200 refrigeration cycle apparatus

Claims

1. A screw compressor comprising:

a casing body having a hollow part;

a screw rotor rotating around a rotation shaft in the hollow part of the casing body;

a semi-cylindrical groove formed on an outer side in a radial direction of the hollow part of the casing body and extending in a direction of the rotation shaft of the screw rotor; and

a discharge port valve contained in the semi-cylindrical groove, wherein

an edge part of the discharge port valve, in which a discharge outlet facing an outer circumference of the screw

rotor is opened, is formed into a stepped shape changing a flow path area of a discharge flow path in a stepwise manner.

2. The screw compressor of claim 1, wherein
the discharge port valve is provided with a rod-shaped coupling part between a member provided with a function of suppressing rotation of the discharge port valve and a member forming part of the discharge outlet to integrate the members, and
the stepped shape is formed in the edge part, in which the discharge outlet is opened, of the member forming part of the discharge outlet.
3. The screw compressor of claim 1 or 2, wherein the discharge port valve is fixed.
4. The screw compressor of any one of claims 1 to 3, wherein the stepped shape includes a single step and end surface inclination of the stepped shape is formed by optimization in two conditions having a large weight of an integrated part load value IPLV.
5. The screw compressor of any one of claims 1 to 3, wherein the stepped shape includes two steps and end surface inclination of the stepped shape is formed by optimization in three conditions having a large weight of an integrated part load value IPLV.
6. The screw compressor of any one of claims 1 to 3, wherein the stepped shape includes three steps and end surface inclination of the stepped shape is formed by optimization in four conditions having a large weight of an integrated part load value IPLV.
7. A refrigeration cycle apparatus comprising the screw compressor of any one of claims 1 to 6.

FIG. 1

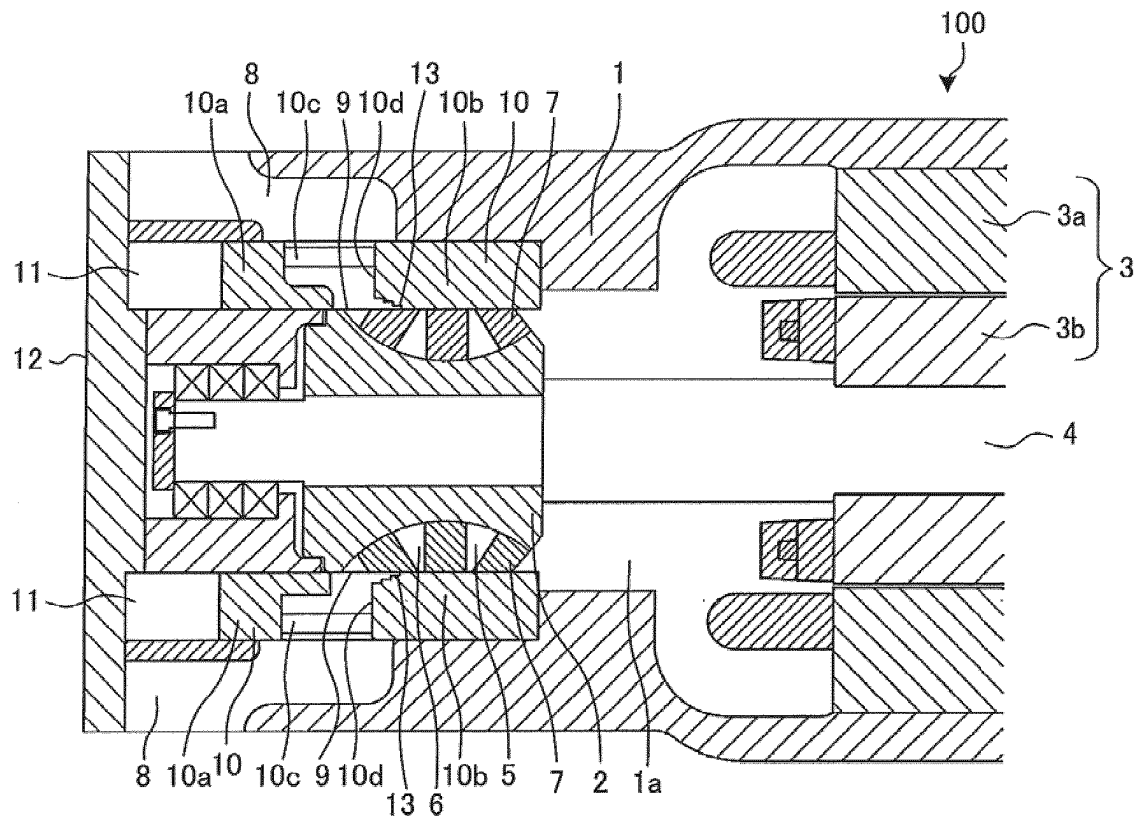


FIG. 2A

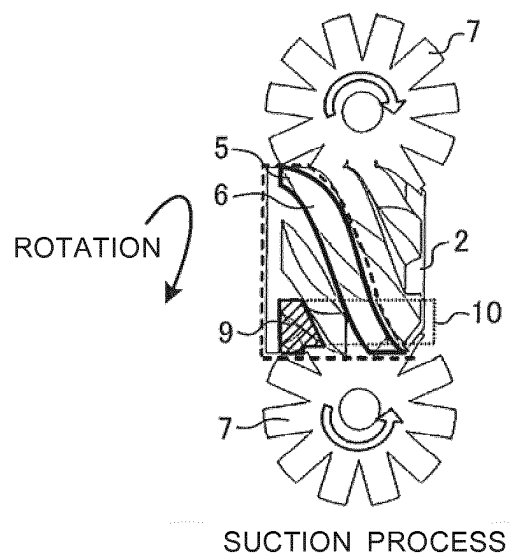


FIG. 2B

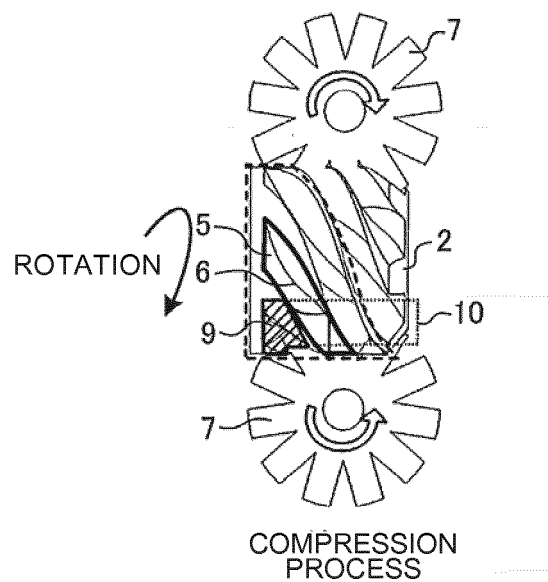


FIG. 2C

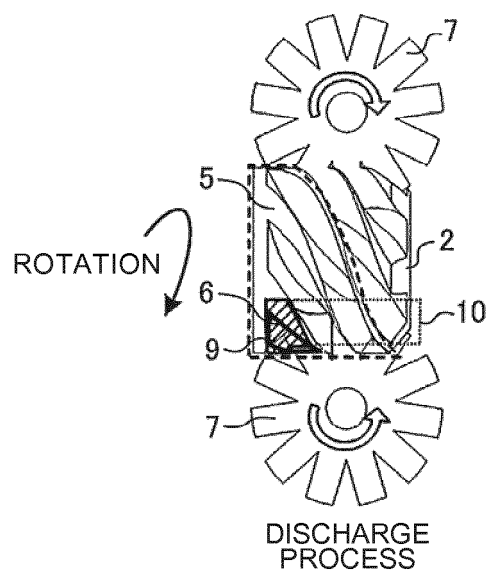


FIG. 3A

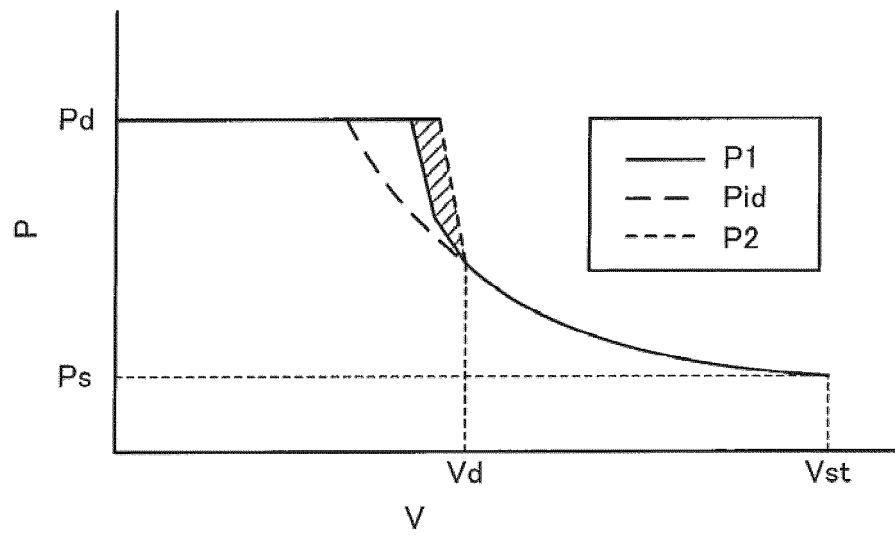


FIG. 3B

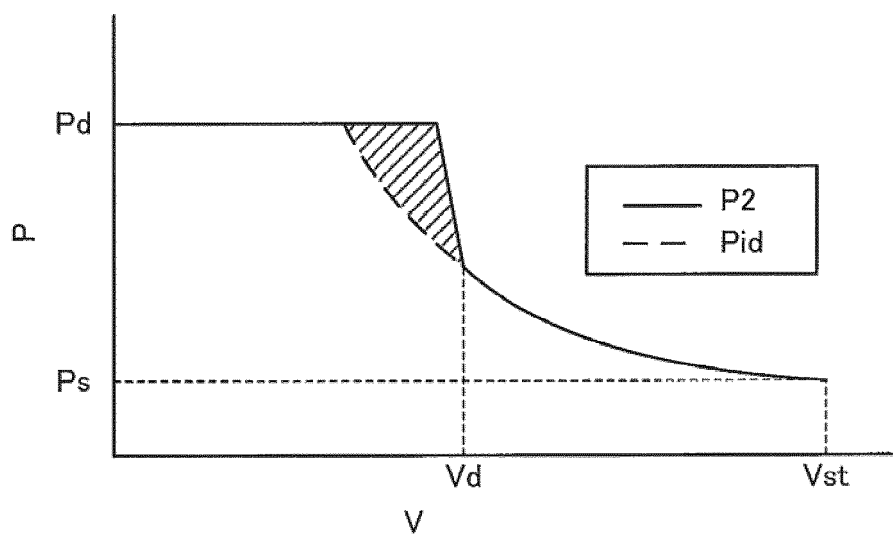


FIG. 4A

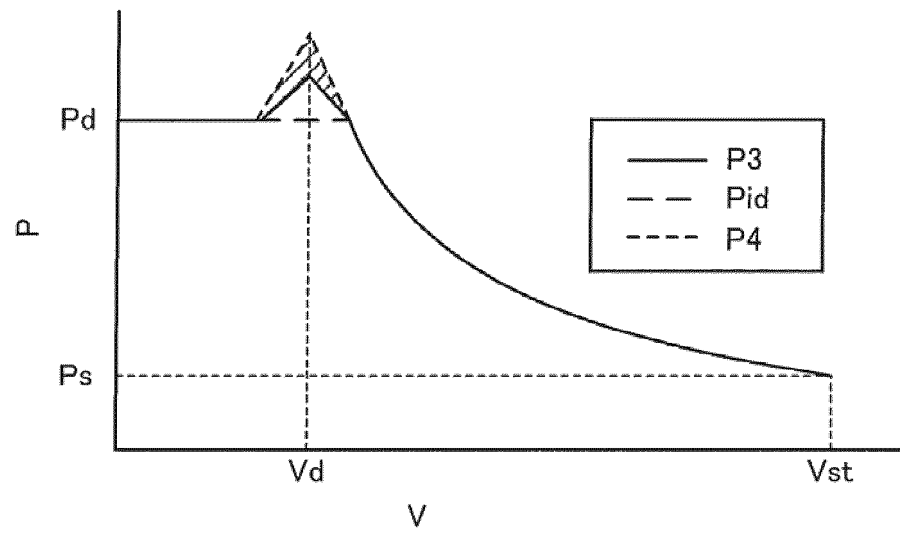


FIG. 4B

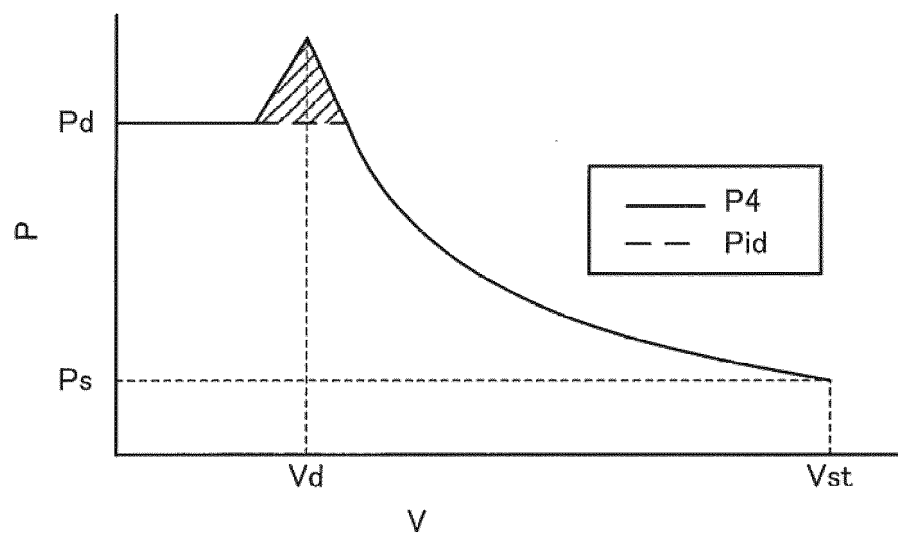


FIG. 5A

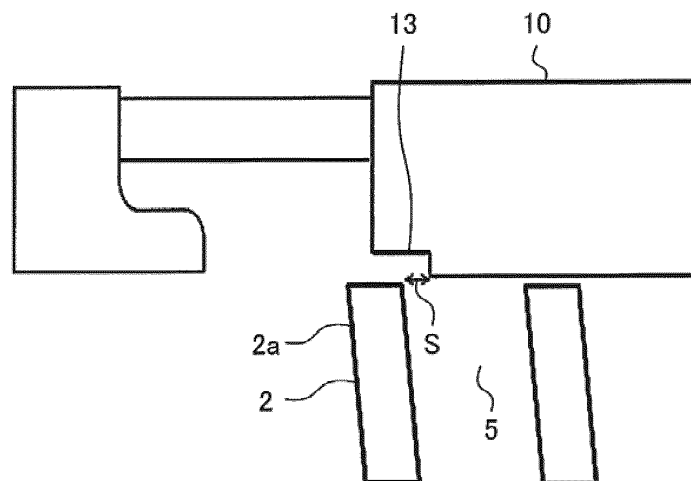


FIG. 5B

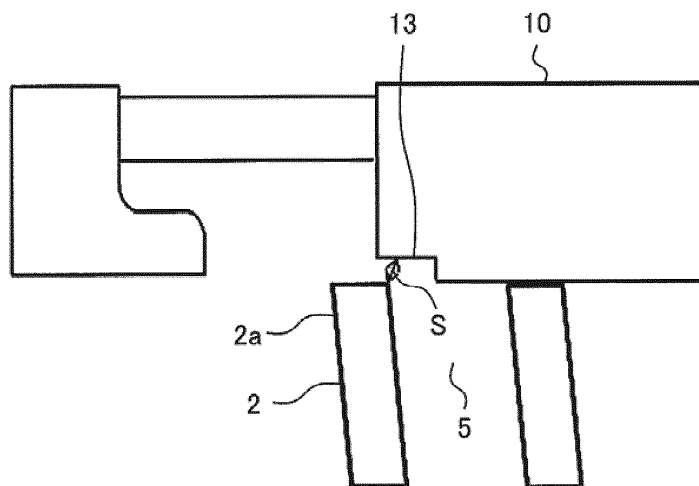


FIG. 5C

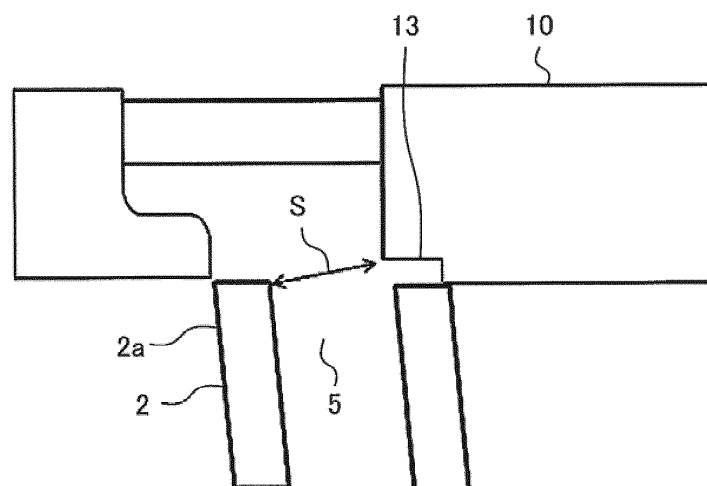


FIG. 6

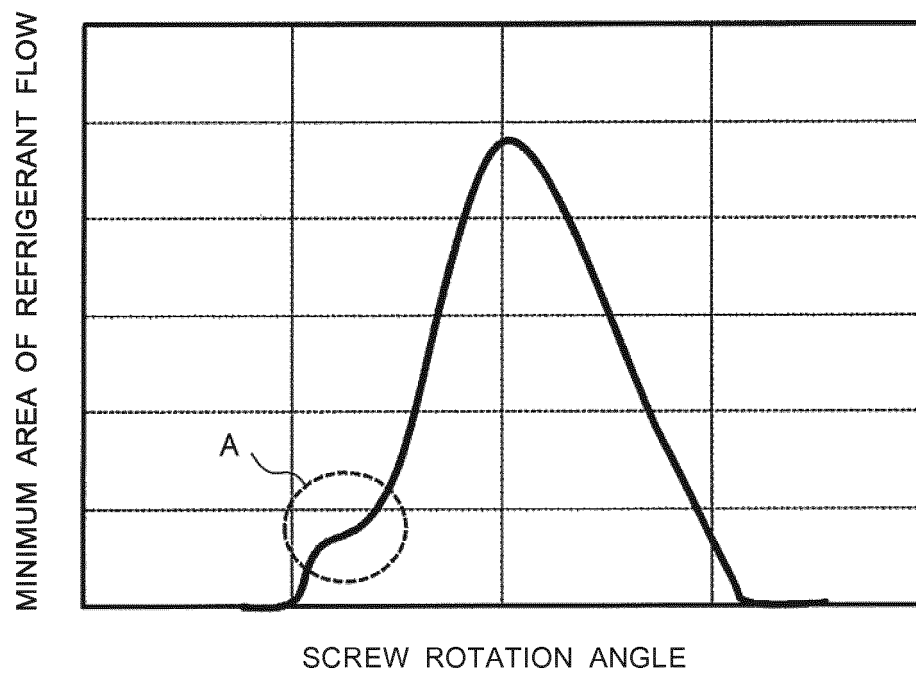


FIG. 7A

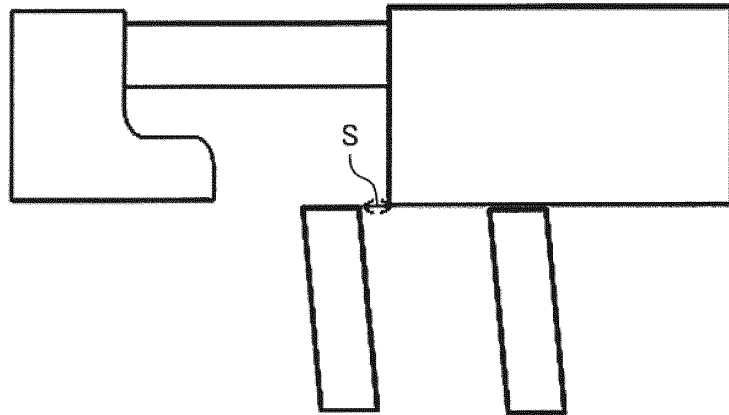


FIG. 7B

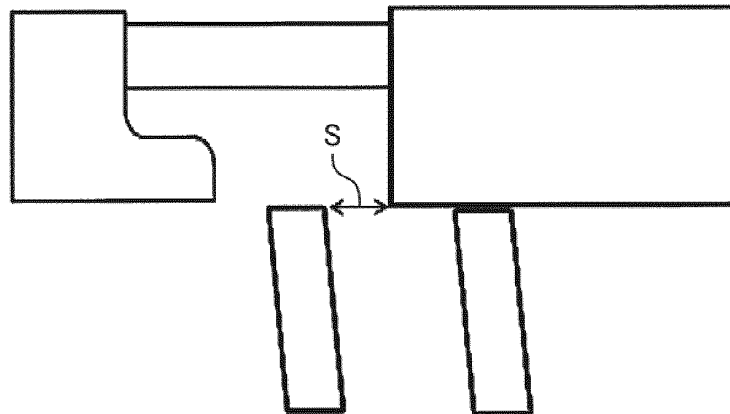


FIG. 7C

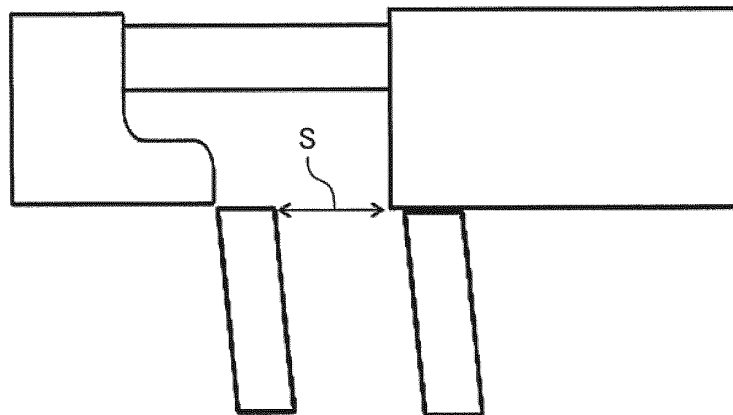


FIG. 8

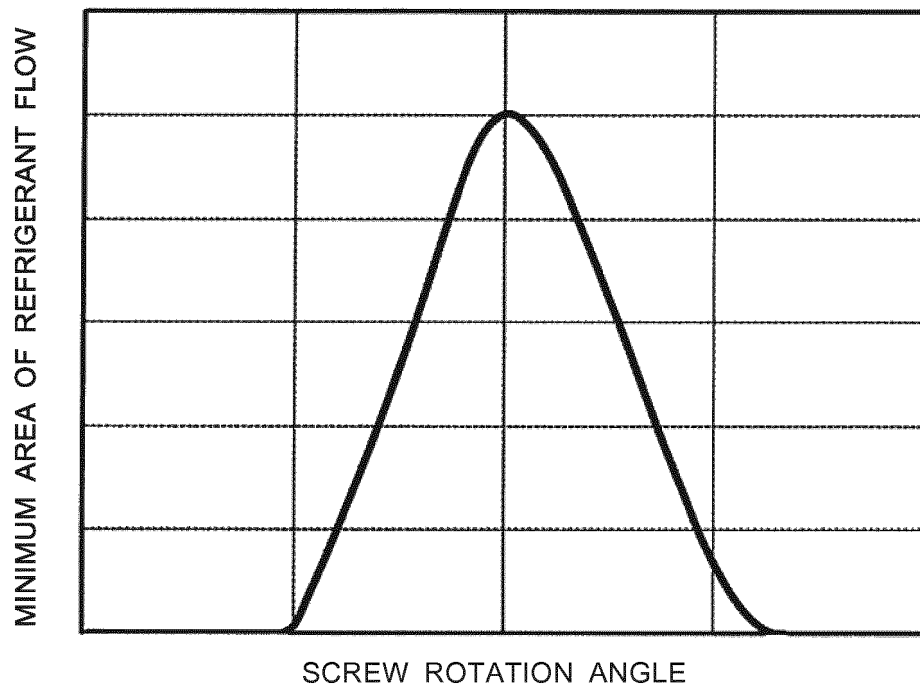


FIG. 9

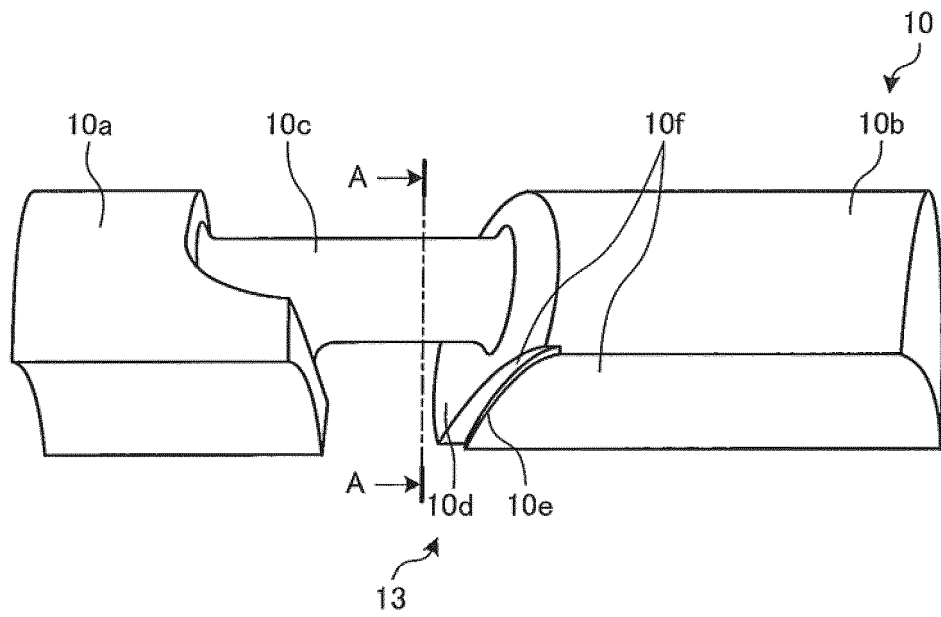


FIG. 10

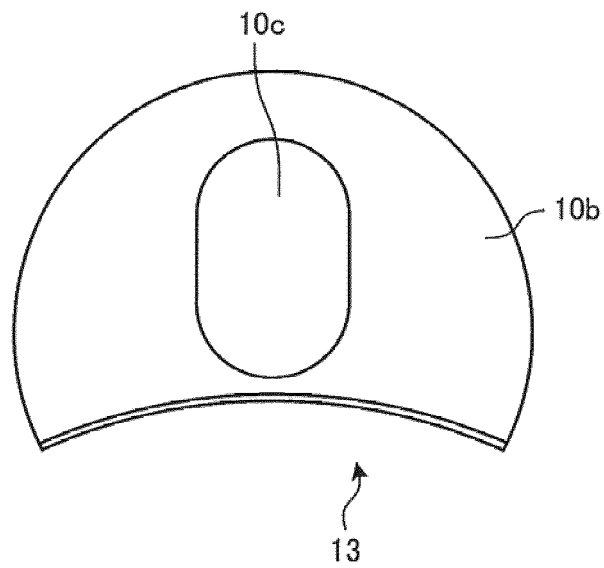


FIG. 11

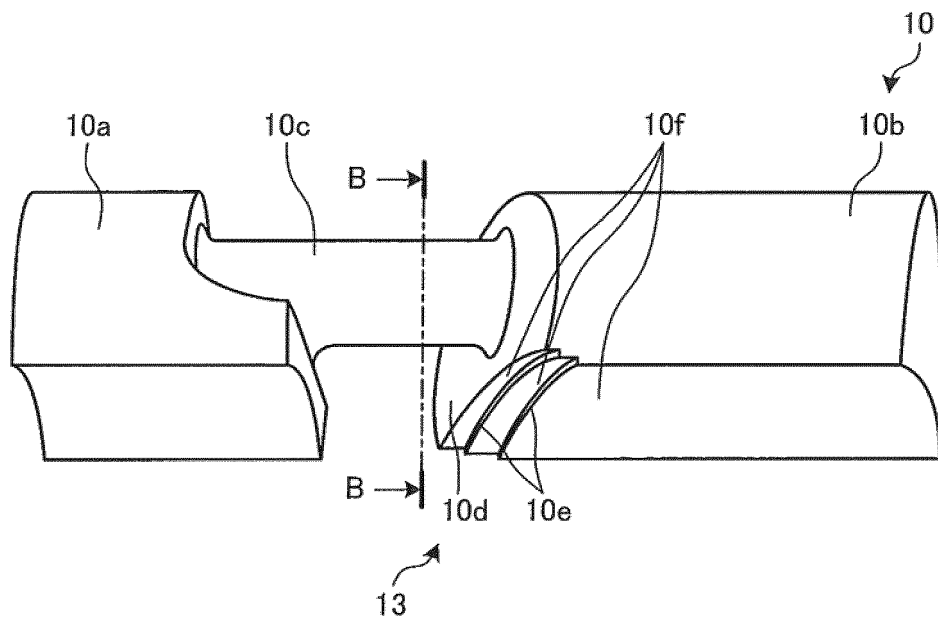


FIG. 12

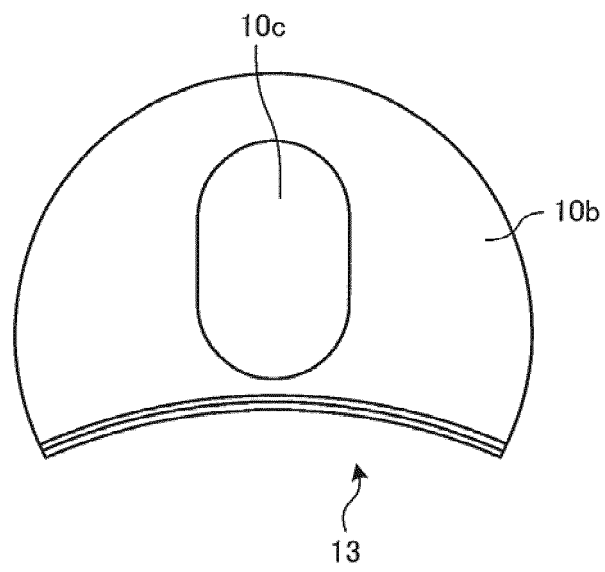


FIG. 13

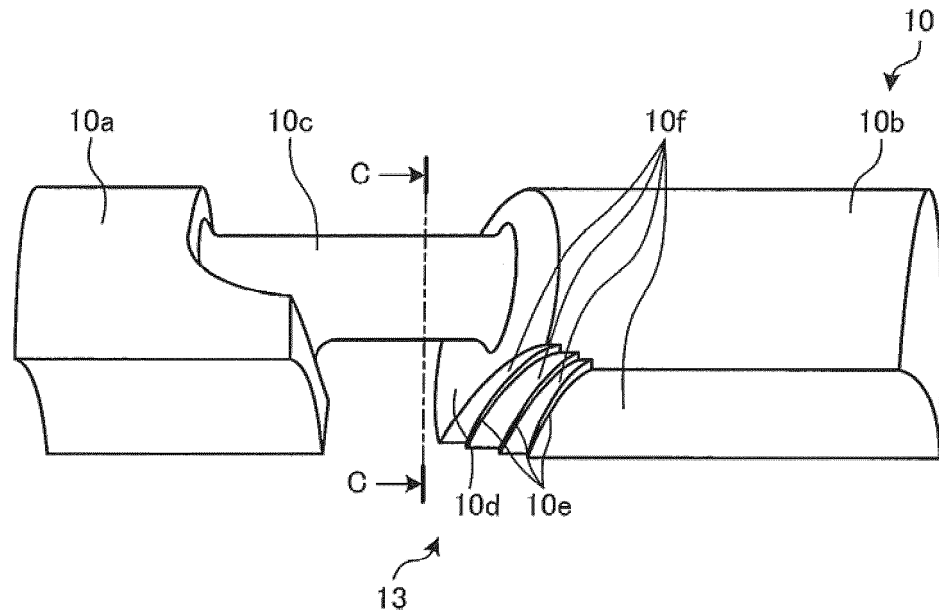


FIG. 14

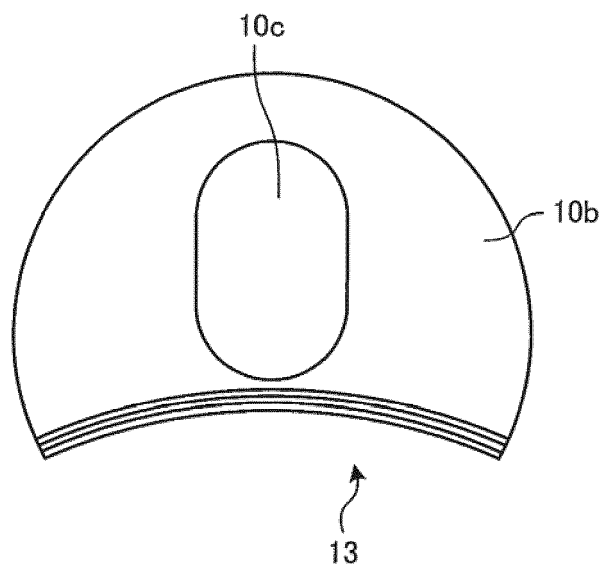
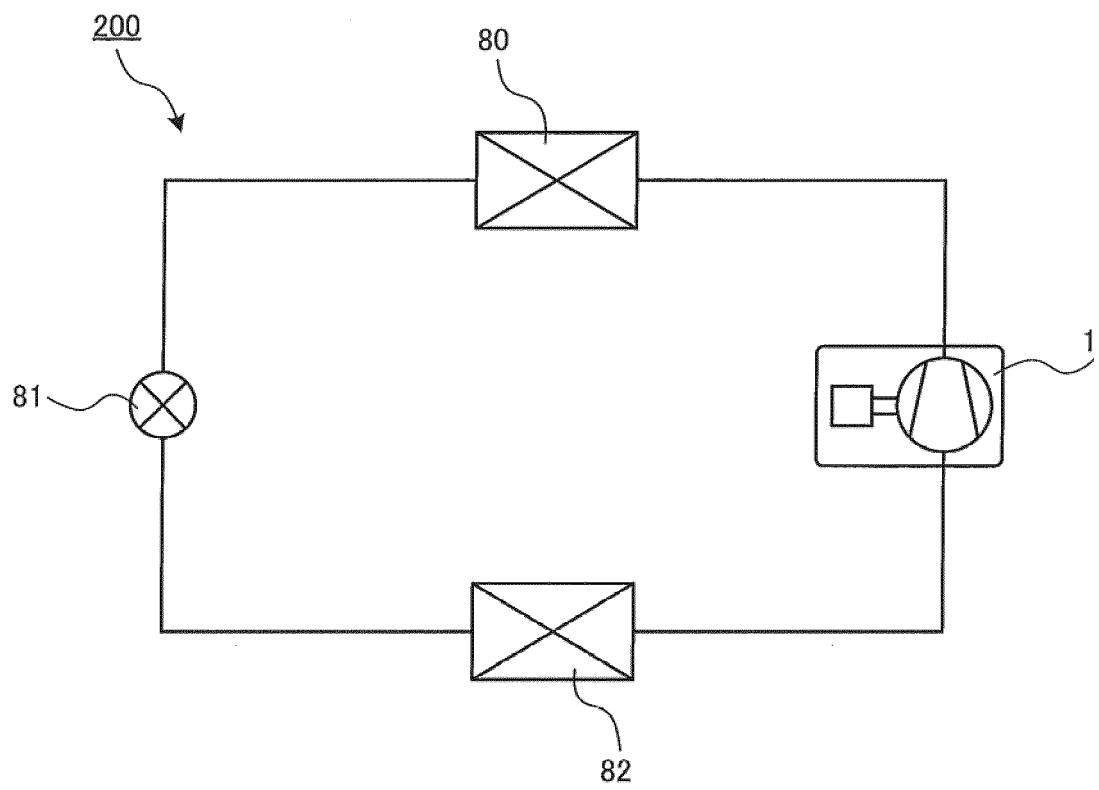


FIG. 15



INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/055145

A. CLASSIFICATION OF SUBJECT MATTER

F04C18/16(2006.01)i, F04C18/52(2006.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

F04C18/16, F04C18/52

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1922-1996 Jitsuyo Shinan Toroku Koho 1996-2016

Kokai Jitsuyo Shinan Koho 1971-2016 Toroku Jitsuyo Shinan Koho 1994-2016

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	JP 2013-127203 A (Mitsubishi Electric Corp.), 27 June 2013 (27.06.2013), paragraphs [0015] to [0017]; fig. 1 to 4 (Family: none)	1-2, 7 3-6
A	JP 2-191890 A (Ebara Corp.), 27 July 1990 (27.07.1990), page 2, upper left column, line 7 to upper right column, line 5; page 2, lower left column, line 10 to lower right column, line 3; fig. 1 to 3 & US 5051077 A column 1, line 61 to column 2, line 34; fig. 2 to 4 & EP 372480 A2	1-7

☒ Further documents are listed in the continuation of Box C.
 ☐ See patent family annex.

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Date of the actual completion of the international search
18 May 2016 (18.05.16)Date of mailing of the international search report
31 May 2016 (31.05.16)Name and mailing address of the ISA/
Japan Patent Office
3-4-3, Kasumigaseki, Chiyoda-ku,
Tokyo 100-8915, Japan

Authorized officer

Telephone No.

INTERNATIONAL SEARCH REPORT

International application No.

PCT/JP2016/055145

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	Microfilm of the specification and drawings annexed to the request of Japanese Utility Model Application No. 24777/1983 (Laid-open No. 131593/1984) (Kobe Steel, Ltd.), 04 September 1984 (04.09.1984), specification, page 6, lines 3 to 17; fig. 2 to 3 (Family: none)	1-7
A	JP 2009-168011 A (Daikin Industries, Ltd.), 30 July 2009 (30.07.2009), paragraphs [0039] to [0040], [0046] to [0048]; fig. 1 to 5 & US 2010/0260620 A1 paragraphs [0057] to [0058], [0065] to [0067] & WO 2009/078178 A1 & EP 2233743 A1 & CN 101896725 A	1-7

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REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

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- JP 62087687 A [0008]